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Effects of ozone on indigenous vegetation in Dolly Sods and Otter Creek Wildernesses

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INTRODUCTION

The Dolly Sods Wilderness (4134 ha) and Otter Creek Wilderness (8094 ha) are located within the Monongahela National Forest (West Virginia, USA). Both Wildernesses are in the Mid-Atlantic Highland geographic region. Elevations range between 805 m to 1256 m at Dolly Sods and 567 m to 1183 m at Otter Creek. These Wildernesses are designated as Class I air quality areas under the Clean Air Act Amendments of 1977. This legislation is intended to safeguard the air quality of Wildernesses and National Parks by minimizing the increase of air pollution above the 1977 level. An increase in air pollution from new emission sources could have a negative impact on resource values.

Perhaps the most significant air pollutant in the eastern United States is ozone. Minimal amounts of ozone may enter the lower atmosphere via natural phenomena, such as: a thunderstorm's electrical discharge, or a hurricane's upper atmospheric disturbance[1]. However, most of the pollutants responsible for the formation of ozone are generated in urban-industrial areas and are then transported to remote areas. Fairly high (greater than .075 ppm) ozone concentrations have been found near Otter Creek and Dolly Sods Wildernesses as the pollutants move eastward with the prevailing wind patterns[2,3]. Typically, the concentrations will be greater during the day at lower elevations and greater during the night at higher elevations[4]. Wolff et al.[5] have reported that some higher elevation sites have a greater average daily ozone concentration and more hours of greater than .080 ppm of ozone than lower elevations sites.

Ozone enters a leaf through the stomates and can produce either acute or chronic injury. Acute injury from ozone is expressed as stippling (small, dark, pigmented areas), flecking, bleaching, and bifacial necrosis[6]. On hardwood and herbaceous plants the injury is usually confined to the upper leaf surface. However, premature senescence (observed as leaf fall or defoliation) can occur from acute ozone injury. Acute injury occurs to extremely sensitive plants, or plants exposed to a high dose of ozone[1,7].

Chronic injury usually occurs to vegetation which is exposed to low concentrations of ozone over a period of time. Some broad-leaf plants will exhibit either stippling or flecking when chronic injury has occurred. Premature senescence of the leaves is also another symptom of chronic injury[1,7].

Both acute and chronic symptoms can be observed in nature, but symptoms cannot be analyzed by chemical means to confirm these observations. Ozone oxidizes rapidly and breaks down immediately upon contact with the plant tissue[1]. Therefore, no signs (such as fungus fruiting bodies) of ozone are present and the diagnosis is based upon symptoms (such as stippling). Field studies use symptoms to identify those plants expressing injury from ozone, and the apparent damage cannot be attributed to ozone with absolute certainty.

Some plants are believed to be useful as bioindicators of ozone within an area[8]. Ozone symptoms have been used in surveys conducted in California[9], Maryland, Virginia, Pennsylvania[10], and Vermont[11]. Anderson et al. have used bioindicators in surveys conducted in South Carolina[12], Virginia[13] and the southeastern United States[14].

Forest Health Protection, USDA Forest Service, has the responsibility to assist the National Forest land manager in determining if air pollution is affecting the vegetation at Class I areas. Native vegetation at the Dolly Sods and Otter Creek Wildernesses have been used to determine if the ozone symptoms were present. This paper presents the survey results for evaluations conducted in the Wildernesses between 1988 and 1990. The objective of the surveys was to determine the distribution and intensity of the ozone damage within the two Wildernesses.

METHODS

The surveys at Otter Creek Wilderness were conducted in mid-July 1988 and late August in 1989 and 1990. At Dolly Sods Wilderness the surveys were conducted in late August or early September for each of the 3 years. Since the plots were established in wildernesses, no permanent markings could be used. Therefore, the site descriptions recorded in 1988 and topographic maps (1:24,000 scale) were used to find the approximate location of the plots in 1989 and 1990.

The plots established in 1988 were located within or adjacent to each of the Wildernesses. Also, the plots had no more than 60% crown closure and the bioindicators were less than 7.6 m tall. For each of the plots, 15 of each type of bioindicator were examined and rated for:

1) Percentage of foliage (in 5% increments) with ozone symptoms (stippling). The values were then later converted to one of the following foliage categories:

   0 = no foliage with ozone symptoms
   1 = 1% to 5% of the leaves with ozone symptoms
   2 = 6% to 25% of the leaves with ozone symptoms
   3 = 26% to 50% of the leaves with ozone symptoms
   4 = greater than 50% of the leaves with ozone symptoms

2) Average amount of ozone symptoms according to the following severity categories:

   0 = absent (no stippling seen on the leaves)
   1 = trace (1% to 5% of the leaf with symptoms)
   2 = light (6%to 25% of the leaf with symptoms)
   3 = moderate (26% to 50% of the leaf with symptoms)
   4 = heavy (greater than 50% of the leaf with symptoms)

3) The intensity rating was later calculated by multiplying the foliage category times the severity category. For example, a plant with 80% of its leaves injured with light symptoms of ozone would be classified as a 8.

RESULTS AND DISCUSSION

A total of 44 plots were established at Otter Creek Wilderness and 28 plots at Dolly Sods Wilderness in 1988. We had difficulty in relocating some of the plots, and some plots were not examined in 1989 or 1990. Therefore, the following includes only those plots where the plants were examined for three consecutive years at Otter Creek or Dolly Sods.

The initial survey at Otter Creek in 1988 was conducted too early in the growing season. A prolonged drought occurred during May through July and no ozone symptoms were present on the bioindicators. Typically, during a drought the stomates will close and ozone cannot penetrate the leaf and cause damage[1]. Ozone symptoms were seen on two bioindicators at Otter Creek in September 1988.

Ozone symptoms have been observed on nine bioindicator plants at Otter Creek and/or Dolly Sods Wilderness (Table I). The plants which have proven the most useful in detecting ozone damage at the Wildernesses have been black cherry, common milkweed, elderberry, and Viburnum sp. The species of Viburnum has not been determined, but southern blackhaw (Viburnum nudum L .) has been reported[15] to be sensitive.

Table I. Plants which showed symptoms of ozone damage at Dolly Sods or Otter Creek Wildernesses.

Common name	Latin binomial
Black cherry	Prunus serotina Ehrh.
Blackberry	Rubus spp.
Common milkweed	Asclepias syriaca L .
Elderberry	Sambucus canadensis L .
Red maple	Acer rubrum L .
Tulip poplar	Liriodendron tulipifera L .
Viburnum sp.	Viburnum sp.
White ash	Fraxinus americana L .
Witch-hazel	Hammamelis virginiana L .

Blackberry and witch-hazel have both been used in these surveys. Occasionally, there was some doubt as to whether or not the stippling seen on these species was in fact caused by exposure to ozone. Furthermore, the blackberry clones have not been increasing in size at many of the plots and the number of plots with 15 blackberry canes has been decreasing. Consequently, both blackberry and witch-hazel will not be used in future surveys.

The species which will be used in future surveys are black cherry, common milkweed, elderberry, tulip poplar, Viburnum sp. and white ash. The stippling symptoms seen on these species are distinct and are believed to be a result of exposure to ambient ozone.

Generally, the frequency of plants with ozone symptoms decreased slightly at Otter Creek between 1989 and 1990 (Table II); whereas, at Dolly Sods the number increased (Table III). Also, the number of plants with moderate or heavy symptoms increased each year for several of the bioindicators (Tables II and III).

Table II. Number of plants in each severity class at Otter Creek Wilderness.

Bioindicator	Year	Absent	Trace	Light	Moderate	Heavy
Black cherry	1989	77	10	10	7	1
	1990	55	10	14	20	6
Common milkweed	1989	21	11	8	9	11
	1990	25	5	10	17	3
Elderberry	1989	82	20	3	0	0
	1990	94	2	2	3	4
Tulip poplar	1989	89	1	0	0	0
	1990	86	2	1	1	0
Viburnum sp.	1989	3	6	2	3	1
	1990	12	0	1	2	0
White ash	1989	25	0	2	2	1
	1990	30	0	0	0	0

Table III. Number of plants in each severity class at Dolly Sods Wilderness.

Bioindicator	Year	Absent	Trace	Light	Moderate	Heavy
Black cherry	1988	59	4	9	9	9
	1989	34	4	15	19	18
	1990	15	16	11	29	19
Common milkweed	1988	101	3	24	19	18
	1989	70	30	34	15	16
	1990	29	32	27	36	41
Viburnum sp.	1988	31	6	1	6	1
	1989	13	4	15	11	2
	1990	15	7	17	6	0

The amount of ozone symptoms has varied between years and sites because of differences in the weather and the amount of ozone precursors present. The influence of drought in 1988 probably reduced the seasonal dosage of ozone which entered the leaves[1] at Dolly Sods and therefore fewer plants had stippling (Table III). Another reason for the differences observed is

some genotypes within a species are not as susceptible to ozone exposure as other individuals of the same species[14]. The plots were located in 1989 and 1990 in approximately the same location as the 1988 plot, but observations have not been made on the same plants each year. Thus the number of plants with ozone symptoms may also be a result of making observations on different genotypes of a species. For example, at Otter Creek there were symptoms seen on white ash. One of the plots is located on the border of the Wilderness in a white ash and black walnut provenance study. The five trees which had symptoms in 1989 are probably susceptible to ozone and no observatons were made on these individual trees in 1990. Others[10] have also observed that white ash is somewhat resistant to ozone damage.

The data collected at each Wilderness has been summarized several ways (Table IV and V). The percentage of plants with the largest number of ozone symptoms were black cherry, common milkweed and Viburnum sp. Others[10, 13] have found tulip poplar to have a greater percentage of the plants with ozone symptoms than what occurred at Otter Creek. Genetic differences of the tulip poplar as well as a smaller sample size (n=90) at Otter Creek may account for the differences.

Table IV. Summary of ozone symptoms at Otter Creek Wilderness.

Bioindicator	Year	Plants with symptoms (%)	Average foliage affected (%)	Average severity *	Average intensity rating
Black cherry	1989	26.6	18.5	0.5	1.9
	1990	47.6	21.5	1.2	3.7
Common milkweed	1989	65.0	26.8	1.6	5.0
	1990	58.3	23.8	1.5	4.5
Elderberry	1989	23.8	10.5	0.4	0.8
	1990	10.5	2.8	0.3	0.8
Tulip poplar	1989	1.0	0.2	0.0	0.0
	1990	4.4	1.9	0.1	0.2
Viburnum sp.	1989	80.0	33.3	1.5	4.6
	1990	20.0	6.0	0.5	1.3
White ash	1989	16.7	10.0	0.4	1.8
	1990	0.0	0.0	0.0	0.0

* 0=none, 1=trace, 2=light, 3=moderate, 4=heavy

Table V. Summary of ozone symptoms at Dolly Sods Wilderness.

Bioindicator	Year	Plants with symptoms (%)	Average foliage affected (%)	Average severity *	Average intensity rating
Black cherry	1988	34.4	34.5	0.9	3.3
	1989	62.2	37.5	1.8	6.5
	1990	82.2	52.8	2.2	8.1
Common milkweed	1988	39.0	39.4	1.1	0.9
	1989	57.8	25.7	1.2	4.8
	1990	82.4	32.6	2.2	6.5
Viburnum sp.	1988	31.1	30.0	0.7	1.6
	1989	71.1	47.4	1.7	6.2
	1990	66.7	42.7	1.3	4.9

* 0=none, 1=trace, 2=light, 3=moderate, 4=heavy

The average severity of the ozone symptoms were trace to light at the Wildernesses (Tables IV and V). The average severity should have been higher for common milkweed and black cherry because many of the plants had premature leaf senescence. Leaves which had fallen to the ground were not included in the ratings. Including the fallen leaves probably would have increased the severity rating to moderate for these two bioindicators. Surveys in the future should account for the foliage loss by estimating the amount of defoliation.

The average intensity ratings (Tables IV and V) is an index which combines the percentage of the foliage affected and the severity of the ozone symptoms. Overall, most of the bioindicators had a low intensity rating of ozone. The results for black cherry and common milkweed in 1990 at Dolly Sods showed a higher intensity rating.

Some of the species used as bioindicators reported here have been used by other investigators in Pennsylvania, Maryland, Vermont and Virginia[10, 11, 13] and the results reported here are similar. Caution should be used when making comparisons to other regions when the data has not been collected the same year. The vegetation survey results from Dolly Sods and Otter Creek should be used for long term trends because there is variation in the outcome between years (Tables IV and V).

Comparing the survey results from different regions can be useful to researchers who conduct experiments aimed at determining the effects of ozone. Experiments conducted during a growing season which produce light symptoms on less than 50% of the foliage may assist resource managers in determining if the symptoms seen in the wildernesses are important. The dilemma of the ozone survey results is: what do the results mean? The response seen on the foliage is probably caused by exposure to ozone, but the response does not mean there is necessarily an adverse impact. Ozone is known to reduce the growth of seedlings[16, 17], but further research is needed with mature trees to determine if symptoms seen indicate there is an adverse impact occurring to the trees in wildernesses.

Growth loss in a timber growing situation is considered an impact, but growth losses to trees in wildernesses caused by ozone exposures may not be an adverse impact. The National Forest land manager is given the responsibility for Class I areas to make sure that emissions from new sources have no adverse impact upon the resource values. An adverse impact would include an increase in the likelihood that genotypes of a plant or tree will die because of direct exposure to ozone, or indirectly because ozone was a stress factor which contributed to the mortality.

An attempt has been made to establish standards for ozone concentrations in Class I areas managed by the USDA Forest Service[18]. The ozone concentration has been divided into green, yellow and red values. The National Forest land manager is expected to know the current level of ambient ozone and then estimate how much additional ozone will be formed after new emissions are added to the Class I areas. The estimates from the new sources are usually determined by the applicant. If the calculated results indicate that the second highest 1 hour average will be .110 ppm or higher, the Wilderness is considered to have a red value. A concentration of .075 ppm or lower for the second highest average places the Class I in the green. The green value predicts that no air quality related value will be adversely impacted; whereas, the red value predicts that at least one air quality related value will be impacted. Values that fall into the yellow (.076 - .109 ppm) area mean that the applicant or the USDA Forest Service need to gather more information to determine if the Wilderness is going to be adversely impacted[18].

The Environmental Protection Agency has established an ozone monitor as part of the National Dry Deposition Network just outside of the town of Parsons, West Virginia. The location of this monitor is at 505 m above sea level, and is within 32 km of the Dolly Sods Wilderness and within 8 km of the Otter Creek Wilderness. The 1988 and 1989 data from this site have been summerized[3]. As previously stated, a drought did occur in 1988. High concentrations of ozone are known to be produced on the back side of stagnant high pressure system[5] and consequently there was 48 hours with an average ozone concentration of .110 ppm. The 1989 growing season was considered wet and no ozone concentrations were reported above .110 ppm, but there were many hours recorded as greater than .075 ppb[3]. Assuming that no new emission sources were adding ozone precursors to the airsheds, the 1988 and 1989 concentrations probably represent two ends of the spectrum.

The Dolly Sods and Otter Creek Wilderness will probably continue to have yellow values for the second highest season ozone concentration. Therefore, the National Forest land manager will need more information to determine if an increase in ozone precursors will impact one or more air quality related values. New studies should be initiated to augment the results obtained from the bioindicators surveys and the ozone monitor. The following are suggestions for new studies which should be implemented. Implementation of each should provide an additional piece of information to the puzzle of whether ambient ozone is affecting the resource values.

1. Conduct a complete vegetation survey to determine which plant species are present and the abundance of each species within the Wildernesses. The vegetation surveys should be accomplished by using aerial photography (1:5,000 scale) techniques coupled with ground based surveys to map the various vegetative associations.

2. Use the aerial photography acquired in step one to determine areas of the Wildernesses which currently have concentrations of tree mortality. The photography can also be used to determine the amount of dieback in crowns of the trees[19]. New imagery should be acquired every 5 years.

3. Establish permanent plots within each vegetative association to monitor the species richness and health of the vegetation. The observations at these plots should include: animal or human damage to the vegetation, annual ratings of the crown condition, a determination of the annual insect and disease impacts, and the amount of foliage affected by ozone symptoms.

4. Cuttings (or seeds) of black cherry, tulip poplar, white ash, and common milkweed should be propagated. Some of the genotypes of these species should have field characteristics of being resistant and susceptible to ozone exposure. These clones can then be challenged under controlled conditions to determine their relative susceptibility. Currently, the USDA Forest Service has a screening laboratory in Macon, GA which could conduct these studies.

5. After the genotypes have been screened the plants should be planted in "vegetative gardens" either within or near the Wildernesses. These plants might be used to determine the relative levels of ambient ozone on a yearly basis. Furthermore, the plants could be used for long term studies on the effects of ozone upon the bioindicators.

6. All endangered plant species which occur in the Wildernesses should be tested for their response to ozone exposure. Also, any plants not known to be sensitive to ozone but have expressed symptoms in the field, should also be fumigated under controlled conditions.

7. Experiments should be conducted which use plant materials developed in step five. One study should use the results from the ozone monitor at Parsons to expose plants during a growing season. Comparisons of growth and other physiological factors could be made with plants that are fumigated with more or less ozone than the ambient concentrations recorded at Parsons.

8. Experiments should be conducted to determine if the ozone symptoms observed in the field have an adverse impact upon the plants.

9. All studies should have quality assurance and quality control.

10. A panel of people representing Federal, State, university and private industry should review project study plans. The panel will determine if the proposed studies should assist the National Forest land manager at acquiring necessary information to determine if ozone is having an adverse impact upon the Wildernesses.

CONCLUSIONS

The ozone surveys have provided information on the presence and severity of ozone symptoms. Ozone symptoms have been observed on nine plants at the Dolly Sods or Otter Creek Wildernesses. Generally speaking, the average severity of the symptoms are from trace to light. Frequent recordings of greater than .075 ppm of ozone have been reported at the Parsons monitoring site and these concentrations could produce the symptoms observed in the field. The impact of ambient ozone levels in the Wildernesses is currently unknown. Further steps should be taken, by conducting more intensive field observations as well as more research to determine the possible impacts. Though symptoms are seen on the foliage of ozone bioindicators, this does not necessarily mean that any air quality related values are adversely impacted. The role of ozone surveys is useful because the long-term observations let the National Forest land manager observe know the trend of symptoms on sensitive plant species.

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